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Industry–university collaboration in rural and metropolitan regions: What is the role of graduate employment and external non-university knowledge?

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ABSTRACT

This study examined to what extent graduate employees' cognitive proximity to universities and firms' external knowledge acquisition strategies are positively associated with the likelihood that firms in rural and metropolitan regions collaborate with universities in Denmark. These links were explored using a dataset that combined data from the Danish Research and Innovation Survey with Danish register data. The results pointed to a positive association between firms' employment of graduates and industry-university collaboration, which was stronger among firms in rural regions than firms in the Copenhagen metropolitan region; however, drawing on external non-university knowledge was similarly associated to industry-university collaboration among firms in rural regions and in the Copenhagen metropolitan region. Regardless of their location, firms were more likely to collaborate with universities if they collaborated with other organisations and were less likely to collaborate with universities if they sought knowledge from other sources, even without necessarily collaborating with them. Although firms in rural regions tended to be farther away from universities than firms in the Copenhagen metropolitan region, the former might be able to collaborate with universities because graduate employees can provide firms with a better understanding of the research conducted there. Thus, firms in rural regions might not need to be geographically proximate to universities in order to collaborate with them.

1. Introduction

Universities are expected to contribute to the economic development of their regions by supporting the efforts of local firms to innovate. In particular, policymakers have promoted the regional missions of universities beyond metropolitan centres in the hope of supporting economic development outside urban agglomerations (Charles, 2006; Evers, 2019; Nilsson, 2006).

Differences in regional characteristics, however, also entail differences in the environments in which industry–university collaboration takes place. Rural regions are more sparsely populated than metropolitan regions and tend to have fewer knowledge-generating organisations such as universities (Tödtling and Trippl, 2005). Furthermore, the university presence in rural regions tends to be limited to a few branch campuses (Charles, 2016). Thus, firms in rural regions typically have to overcome a larger geographical distance to collaborate with universities (Johnston and Huggins, 2016).

Because firms that are geographically closer to universities have been found to be more likely to collaborate with universities than firms that are farther away, owing to the advantages of geographical proximity in facilitating the transmission of complex, tacit knowledge through face-to-face interactions (D'Este et al., 2013; D'Este and Iammarino, 2010; Drejer and Østergaard, 2017), geographical distance might pose an obstacle to industry–university collaboration for firms in rural regions. The relative absence of universities in rural regions might also imply that universities are less likely to become a usual collaboration partner among firms in rural regions.

However, forms of proximity other than geographical might be more relevant for determining how inter-organisational collaboration takes place (Boschma, 2005). In particular, firms have been found to be more likely to collaborate with universities if they employ graduates from that university, suggesting that graduate employees can facilitate cognitive proximity between their current employers and universities by providing firms with a deeper understanding of university research and how universities function as organisations, increasing the ability of firms to integrate university knowledge (Drejer and Østergaard, 2017). However, little is known so far on how the relationships between graduate employment and industry–university collaboration might differ between firms in rural regions and their metropolitan counterparts.

Secondly, although firms that draw on external non-university knowledge have been found to be more likely to collaborate with universities (Hewitt-Dundas et al., 2019; Laursen and Salter, 2004), little is known on how drawing on this knowledge might differently affect industry–university collaboration among firms in rural regions and those in

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metropolitan regions. Previous research has found that firms in sparsely populated locations were more likely to rely on collaboration channels with other organisations than firms in densely populated locations. By collaborating with these organisations, firms in sparsely populated locations might gain access to knowledge that cannot be acquired through unplanned, informal interactions in their home regions (Jakobsen and Lorentzen, 2015). These collaboration channels can also entail extra-regional partners, if no suitable partners are to be found in their home region (Drejer and Vinding, 2007; Grillitsch and Nilsson, 2015).

This paper's initial aim was to contribute to the industry–university collaboration literature by exploring the links between graduate employment and industry–university collaboration in innovation among firms in rural regions and firms in metropolitan regions. A second aim was to compare, between firms in rural and metropolitan regions, the relationship of drawing on external non-university knowledge to industry-university collaboration in innovation. In doing so, the following research question was addressed:

To what extent are graduate employment and drawing on external knowledge net of universities associated with collaboration in innovation between universities and firms in rural and metropolitan regions?

To date, few papers have compared how industry–university collaboration takes place in different regional contexts. In particular, not much is known about how industry–university collaboration takes place in rural regions relative to other types of regions (Johnston and Huggins, 2016); the literature is mostly focused on factors associated with industry-university collaboration regardless of the regional location (D'Este et al., 2013; D'Este and Iammarino, 2010). This paper helps to close this gap by using a dataset that combines research and innovation survey data and register data for 4772 firms in Denmark involved in conducting innovation activities between 2009 and 2015. With this dataset, logistic regression analyses were performed on the likelihood that firms collaborate with universities located in Denmark.

The study adds to the industry-university collaboration literature by confirming that there was a positive association between graduate employment and industry-university collaboration in innovation, but this association was stronger among firms in rural regions than their metropolitan counterparts. Secondly, firms in rural regions that drew on external knowledge net of universities were not more likely to collaborate with universities in innovation than similar firms in metropolitan regions.

By relying on the cognitive proximity of graduate employees to university research, firms in rural regions appeared to overcome the obstacles that their location might pose to industry–university collaboration in innovation. Conversely, the co-location of firms and universities might be enough to facilitate industry-university collaboration in innovation in metropolitan regions. There is also the possibility that graduate employees' social ties to staff from their *alma mater* universities facilitate collaboration with these universities. However, the dataset used in the present paper did not allow for testing this possibility, and further research would be required. Policymakers interested in facilitating the involvement of firms in rural regions in industry–university collaboration might see in graduate employment a channel through which more of these firms could benefit from collaboration with universities.

The paper is structured as follows. The next section presents the literature review and hypotheses. Afterwards, the research methods used in the paper are outlined. A third section presents the empirical analyses. Finally, the concluding section discusses the main findings of the paper.

2. Literature review

2.1. How can graduate employees connect firms in rural and metropolitan regions with universities

Firms in rural and metropolitan regions operate in different regional environments, and these differences can have consequences for a firm's innovation activities. Tödtling and Trippl (2005) and Zukauskaite et al. (2017) point out that firms in rural regions operate in organisationally thin regions, with few or no urban agglomerations and a narrow variety of knowledge-generating organisations, such as universities. The characteristics of metropolitan regions are markedly different because these are predominantly urban, organisationally thick and diverse regions; home to a broad range of knowledge-generating organisations. Indeed, Charles (2016) shows that in rural regions university presence tends to be limited to a few branch campuses.

These inter-regional differences mean that firms in rural regions might face (when compared to firms in metropolitan regions) an obstacle to industry–university collaboration because geographical proximity has been observed to facilitate collaboration between firms and universities, owing to the role of geographical proximity in enabling face-to-face contacts between partners. D'Este et al. (2013) and D'Este and Iammarino (2010) suggest that frequent face-to-face encounters can facilitate the transmission of complex and tacit knowledge between firms and universities and can prevent misunderstandings that might emerge when trying to align the routines of the firms and universities. Furthermore, the relative absence of universities in rural regions might imply that these institutions do not appear to firms in these regions as feasible collaboration partners, at least not as readily.

However, geographical proximity is not a necessary condition for the transmission of knowledge between two or more parties, and other forms of proximity might suffice. Aguiléra et al. (2012) and Boschma (2005) argue that knowledge transmission is feasible among organisations that are cognitively proximate, that is that they possess similar knowledge bases; the same goes for organisations that are socially proximate, those that share social ties and therefore can more easily establish trust-based relationships. Nevertheless, these two forms of proximity facilitate knowledge transmission in different ways. When two parties are cognitively proximate, the similarity enables them to better understand each other's knowledge base. Furthermore, the compatibility between the parties' knowledge bases suggests that it will be easier for them to integrate the knowledge they exchange. Meanwhile, when two organisations are socially proximate, trust-based relations between employees in the two organisations enable the transmission of complex knowledge because the parties can commit to the effort required to facilitate the transmission of this knowledge beyond the dictates of market incentives.

Based on the previous discussion, geographical proximity might not necessarily be a requirement for knowledge transmission between firms and universities and the use of industry–university collaboration to transmit knowledge between firms and universities. The industry–university collaboration literature has pointed out that graduate employees can help in connecting firms and universities (Breschi and Lissoni, 2001; Drejer and Østergaard, 2017; Østergaard, 2009). Østergaard (2009) argues that engineers educated at a nearby university or that have collaborated in projects with researchers from it are more likely to have informal contacts with the university. The networks these engineers maintain with a focal university, he argues, allow the engineers to have knowledge of which research is being conducted there and which researchers from that institution they can approach. Thus, engineers are key to firms because they help the firm understand university knowledge—providing cognitive proximity—and also because their social networks enable the firm to know which university researchers should be approached, contributing to the social proximity between their employers and the university where they obtained their degrees.

Similarly, Drejer and Østergaard (2017) observed that firms are more likely to collaborate with a specific university if they have employees that hold a degree from that university. These findings were interpreted by Drejer and Østergaard (2017) as an indication that graduate employees can provide social proximity between their firms and the universities where they obtained their degrees because graduate employees can help firms approach university staff through their social networks; thanks to employee social ties, firms have an idea of who is who at the university. In addition, a certain university may be preferred over others in a discipline in which it specialised if employees hold degrees from this discipline; a finding that

Drejer and Østergaard (2017) interpret as an indication that graduate employees' discipline-related knowledge can enable similarities between the knowledge bases of the focal firm and the university in terms of specific, discipline-related cognitive proximity.

Metropolitan regions are argued to have, relative to rural regions, a higher density of university graduates in their workforce because of various factors, such as the presence of pools of specialised labour serving agglomerated industries that provide a better match between graduates' job searches and employer needs (Rodríguez-Pose and Fitjar, 2013; Scott, 2010; Storper and Scott, 2009); a more open, tolerant environment in cities, which might be attractive to university-trained professionals (Florida, 2002); and a greater concentration of emerging, high-technology sectors that demand employees with university qualifications (McCann, 2008; Storper, 2018). However, in metropolitan regions, geographical proximity might suffice for industry–university collaboration to take place because firms in these areas are typically co-located with more than one university. In contrast, for firms in rural regions, it might be more relevant whether they employ university graduates because these firms are not co-located near universities. Because of their university education, graduate employees might provide these firms with knowledge of university research and how universities function as organisations. Thanks to this knowledge, firms in rural regions that employ university graduates might be cognitively proximate to universities and so, are able to interpret and absorb university knowledge. The first hypothesis summarises this distinction:

H1. There is a positive association between employing university graduates and the likelihood of collaborating in innovation with universities, and this association is stronger among firms in rural regions than for similar firms in metropolitan regions.

Based on the previous discussion, it is also possible that graduate employees possess social ties to staff from their *alma mater* universities, providing social proximity between these universities and the firms where they are currently employed; however, the dataset used in the present paper does not contain information on social ties between firms and specific universities (see Section 3). Therefore, the hypothesis does not explore the relevance of social ties between firms and universities for industry-university collaboration.

2.2. The role of drawing on external knowledge net of universities in the collaboration of firms in rural and metropolitan regions with universities

Firms draw on external knowledge to increase their capacity to innovate (Criscuolo et al., 2018; Laursen and Salter, 2006; Rosenkopf and Nerkar, 2001). Within this literature, Laursen and Salter (2004) have also found that those firms that seek knowledge from a diversity of sources other than universities are also more likely to draw knowledge from universities. These other sources might include other firms (such as suppliers, customers, and competitors) but also may be public research organisations and sources other than organisations (such as conferences and the technical press). More recently, Hewitt-Dundas et al. (2019) have argued that by drawing knowledge from other organisations that are not universities, firms can develop knowledge-acquisition capabilities and cognitive proximity to universities. This is because collaborations with third-party organisations increase the stock of knowledge available to firms, and the greater the knowledge stock, the greater a firm's capacity to integrate further knowledge is. In addition, collaboration experience increases a firm's ability to select those partners that fit best its knowledge needs. In this way, firms are cognitively closer and more likely to collaborate with universities.

Jakobsen and Lorentzen (2015) contend that firms in rural regions will show a stronger preference for formalised collaboration channels, because drawing on external knowledge through unplanned, informal interactions is less likely to be an effective strategy for innovation in regions with a limited stock of knowledge-generating organisations. That is, unplanned interactions are less likely to take place in regions with few knowledge-generating organisations. Conversely, in organisationally dense regions like metropolitan areas, informal interactions might suffice for obtaining knowledge.

Furthermore, Drejer and Vinding (2007) argue that there are inter-regional differences in firms' propensities to collaborate for innovation with extra-regional organisations, finding that in sparsely populated locations firms with high levels of absorptive capacity—that is, the capacity to acquire, assimilate and integrate new knowledge (Cohen and Levinthal, 1990)—were more likely to have their main collaboration partner abroad. These extra-regional collaborations can compensate for the lack of suitable partners in the firm's region, and allow firms to gather knowledge not available in the region in which they are located. Similar arguments are proposed by Grillitsch and Nilsson (2015), who found that among firms of a relatively large size and absorptive capacity,[1] those in locations with a sparse population of professionals working on technology-related fields were more likely to have formal collaboration arrangements than firms in more densely populated regions, and these collaboration arrangements were more likely to involve extra-regional partners.

By collaborating with organisations other than universities, firms might develop knowledge-acquisition capabilities and thus cognitive proximity to universities. Hence, industry–university collaboration might be more likely for both firms in rural and metropolitan regions if they have collaboration channels to acquire external non-university knowledge. However, firms in rural regions are more likely to rely on these channels than their metropolitan counterparts. Because geographical proximity is less likely to support firms in rural regions' collaboration with universities, it is more likely that firms in rural regions that collaborate with universities do so because they draw on external non-university knowledge, which also contributes to their cognitive proximity to universities. The second hypothesis summarises these arguments:

H2. There is a positive association between drawing on external knowledge net of universities and collaborating in innovation with universities, and this association is stronger among firms in rural regions than among similar firms in metropolitan regions.

3. Research methods

3.1. Data sources

In this paper, data are combined from two datasets managed by Statistics Denmark: the integrated database for labour market research (IDA, in Danish) and the Danish Research and Innovation Survey, which is the Danish version of the Community Innovation Survey. The IDA is a register dataset that combines personal-level data on the Danish population with data on the population of workplaces in Denmark (Timmermans, 2010).

The percentage of firms that collaborate with Danish universities as part of their innovation activities has fluctuated between 2009 and 2015 with a tendency for higher collaboration in even years and lower in odd years, for example, shifting from 12% in 2014 to 9% in 2015 (Erhvervsstyrelsen, n.d.). A likely cause for this variation is the design of the Danish Research and Innovation Survey questionnaires; during odd years, the questionnaires include more questions about research and development (R&D) activity, and a lower number of firms appear to report collaboration with universities as a likely result of respondent fatigue.[2] Taking into account that the firms' propensity to report collaboration with universities can vary from year to year, a pooled sample

[1] Measured as the proportion of employees in the firm with a high level of technological competences (Grillitsch and Nilsson, 2015, pp. 306–310).

[2] This pattern is reproduced in practically all the years in the time series reported by Erhvervsstyrelsen (n.d.). The only exception appears to be in the shift between 2012 and 2013, since the percentage of firms that reported collaboration with universities was the same between these two years, probably because of the crisis that affected Denmark in those years.

approach was chosen in this study. The following waves of the Danish Research and Innovation Survey were included: the 2011 wave, where firms were asked for data covering collaboration during the 2009–2011 period; the 2012 wave, covering 2010–2012; the 2013 wave, covering 2011–2013; the 2014 wave, covering 2012–2014; and the 2015 wave, covering 2013–2015. The combined dataset covered the time period from 2009 through 2015. Because the final sample was a merger of cross-sections, in this study, it was not possible to study causal relations.

Each wave included all the firms in the population with more than 100 full-time equivalent employees (FTEs). The lower the number of FTEs, the lower the likelihood of being selected for a wave. The surveys were compulsory, minimising the number of non-responses (Statistics Denmark, 2015, 2012).[3] When constructing the combined dataset, the firms were selected so that they occurred only once. This was done by ordering observations according to their identification number. An assigned random digit was then assigned, and in a subsequent step, observations with repeated identification numbers were excluded. Through this procedure, only one observation per firm was included in the combined dataset, and the firms from one wave were not more likely to be included than firms from other waves.

After excluding repeated observations and excluding firms that did not engage in innovation activities[4] as well as firms that had missing or extreme values, the final combined dataset had 4772 observations of which 955 corresponded to the 2011 wave, 909 to the 2012 wave, 919 to the 2013 wave, 931 to the 2014 wave and 1015 to the 2015 wave. When analysing the dataset, the calibre weights provided by Statistics Denmark were applied (Månsson and Stoltze, 2011, pp. 78–80).

3.2. Dependent variable

Binomial logistic regressions were run on the likelihood that firms reported having collaborated with one or more Danish universities (*COLLAB_UNI*). The data for the variable was obtained from the Danish Research and Innovation Survey, taking the value “1” if the firm reported collaborating with one or more universities and also reported these collaborations to be relevant to its innovation activities or “0” otherwise.

3.3. Explanatory variables

To test Hypothesis 1, the study included a variable capturing the percentage of employees in the firm that held a university degree (*SHAREGRAD*), a variable capturing the focal firm's type of region (*REGION*) and an interaction term (*REGION*SHAREGRAD*). The data for *SHAREGRAD* and *REGION* were obtained from the IDA database. For each observation, *SHAREGRAD* was the percentage of employees holding a university degree in a firm averaged for all the years included in a wave of the Danish Research and Innovation Survey (e.g., for a firm that participated in the 2011 wave, *SHAREGRAD* was the average percentage of graduates in their workforce between 2009 and 2011). The graduate employees might have obtained their degrees in a Danish university or abroad. For the 2014 and 2015 waves, *SHAREGRAD* was an average of the years between 2012 and 2013 because the data required to construct the variable were only available until 2013; however, a comparison of the average and median values of *SHAREGRAD* across the years did not indicate substantial variations over time (those statistics are not presented in this paper). The data for *REGION* only covered the location of the focal firm in the last year of each wave, but a firm's location was not expected to change substantially on a year-by-year basis. *SHAREGRAD* has also been previously used as a proxy for a firm's absorptive capacity (Drejer and Østergaard, 2017); however, *SHAREGRAD* differs from other variables used to control for a firm's absorptive capacity (see below) in that graduate employees can provide knowledge of how universities function as organisations because of their university education. By employing university graduates, firms should be better able to understand how to interact with universities and thus, be cognitively closer to university research.

Whereas *SHAREGRAD* was used in the present paper to assess whether graduate employees contributed to the cognitive proximity between firms and universities, this variable was not used to capture whether graduate employees contributed to the social proximity between these types of organisations. Although it might be the case that firms are more likely to collaborate with specific universities because of the social ties between graduate employees and researchers from their *alma mater* universities, *SHAREGRAD* could not discern whether these social ties were in place and contributed to the social proximity between firms and universities. Hence, in this study, any results concerning *SHAREGRAD* were interpreted in connection to the role played by graduate employees in overcoming cognitive distance to universities.

Previous industry–university collaboration research has operationalised the ways firms draw on external non-university knowledge by counting the number of types of knowledge sources, whether these were organisations or not, that a firm might source knowledge from on an arm's length basis, though not necessarily involving collaboration (Laursen and Salter, 2004). Another approach involves counting the number of types of organisations and the net of universities that a firm collaborates with as part of its innovation activities (Drejer and Østergaard, 2017). Just as collaborative relationships between firms and universities require more commitment from the firm than industry–university links where there is no collaborative relationship (Perkmann and Walsh, 2007), collaborative relations might require the firm to commit more resources than drawing on external knowledge through arm's length non-collaborative relations.

To test Hypothesis 2, both approaches to drawing on external non-university knowledge were applied. The number of types of organisations, net of universities, public research institutes and approved technological services institutes that a firm collaborated with as part of its innovation activities were calculated (*COLLAB*); the number of types of sources, whether these were organisations or not, that a firm drew knowledge from, on an arm's length basis, excluding universities, public research institutes, scientific journals and conferences was also calculated (*SOURCE*). The data for these variables were gathered from the Danish Research and Innovation Survey, where respondents were asked to report whether their firms considered items from a list of knowledge sources as relevant to the firm's idea development activities and the completion of innovation activities. *SOURCE* included: clients, suppliers, competitors, consultants and professional/industrial organisations. Responses for each of these sources were added so that “5” corresponded to firms that considered all types at least somewhat important. In the survey, respondents also had to report whether their firms collaborated with a list of different types of organisations as part of their innovation activities. *COLLAB* included: suppliers, customers, competitors, firms in other industries, consultants, public service providers and other public partners. Values for *COLLAB* ranged from “0” to “7”, depending on the number of types of organisations with which firms collaborated. Both *COLLAB* and *SOURCE* interacted with *REGION*. The low correlation between *COLLAB* and *SOURCE* ($r = 0.19$, statistically significant below the 1% threshold) suggests that they fulfil different functions in a firm's innovation strategy. Indeed, based on the points raised by Jakobsen and Lorentzen (2015), one could argue that

[3] Statistics Denmark derives its statistical population from the Business Statistical Register, defining a frame of enterprises and deleting certain activities and firms with few employees. The final frame population was also weighted (Statistics Denmark, 2015, 2012).

[4] These are the introduction of new or significantly improved products, manufacturing processes, operations, organisational structures or marketing techniques, as well as ongoing or abandoned innovation activities during the survey period.

SOURCE corresponds to unplanned informal forms of knowledge acquisition. However, *SOURCE* is more likely to include planned interactions because the firm respondents were able to note the number of knowledge source types from which they drew.

REGION was operationalised as a categorical variable, capturing whether the firm's main workplace was located in a rural region, a metropolitan region or an intermediate region (i.e., a region with a population density in between that of typical rural and metropolitan regions). The benchmark corresponded to firms in a metropolitan region. Firms in intermediate regions were more likely to be co-located with universities than firms in rural regions because intermediate regions tended to have main university campuses (Isaksen and Trippl, 2014; Nilsson, 2006). However, the focus in the remainder of this paper is on the differences between firms in rural and metropolitan regions, because the research question and hypotheses focus on industry-university collaboration in rural and metropolitan regions.

The classifications used in *REGION* were based on the list of the functional urban areas of Denmark provided by the OECD, which also includes the municipalities comprising these urban areas (OECD, n.d.). The OECD defines a functional urban area as a location with at least 50,000 inhabitants, including a core of densely populated contiguous municipalities in which at least 50% of the area has a population density equal to or above 1500 inhabitants/km^2 and an urban hinterland of municipalities in which at least 15% of the employed population commutes to work in the core municipalities.[5] The OECD defines a functional urban area with 500,000 inhabitants or more as a metropolitan area (OECD, 2012, pp. 29–34).

In Denmark, the OECD (n.d.) identified five functional urban areas, which were from the largest to the smallest, Copenhagen, Aarhus, Odense, Aalborg and Esbjerg. With an average population of 1,839,146 inhabitants between 2009 and 2015, Copenhagen was the only metropolitan area. At the other extreme, the Esbjerg area had an average population of 168,528 inhabitants between 2009 and 2015 (Statistics Denmark, n.d.).[6] The municipalities of the Copenhagen metropolitan area were categorised as a metropolitan region, and the municipalities in the other functional urban areas were intermediate regions. Finally, those municipalities that did not belong to any functional urban area were categorised as rural regions. Fig. 1 shows the location of each type of region, and Table A1 in the Appendix provides a list of the municipalities included in each functional urban area.

The traits of the rural regions differed from those of the intermediate regions and the Copenhagen metropolitan region. Macro data from Statistics Denmark revealed an average population density between 2009 and 2015 of 79.22 inhabitants/km2 for the rural municipalities, 130.93 inhabitants/km2 for the intermediate municipalities and 775.15 inhabitants/km2 for the metropolitan municipalities (Statistics Denmark, n.d.). Secondly, Fig. 1 shows that the rural regions did not have main university campuses. All the intermediate regions except Esbjerg had main university campuses, and the Copenhagen metropolitan region had five universities (Danish Ministry of Higher Education and Science, n.d.). More differences are shown in the descriptive statistics (Section 3.5).

3.4. Control variables

The analyses control for the use of internal knowledge sources (Criscuolo et al., 2018; Laursen and Salter, 2006) by including *SOURCE_INT*, which was based on data from the Danish Research and Innovation Survey. Its values were “0” if internal knowledge sources were not considered important for the firm's idea development activities, “1” if they were considered somewhat important and “2” if very important.[7] The benchmark was “1”, because the size of the category was large enough to be a reference category.[8]

Firms that draw on external non-university knowledge also tend to draw on knowledge from universities (Laursen and Salter, 2004). To control for the propensity of firms to draw knowledge from universities or similar sources, the regression models included *SOURCE_ACADEMIC*, which controlled for arm's length knowledge sourcing, and *COLLAB_ACADEMIC*, which controlled for collaborative links. Both were based on data from the Danish Research and Innovation Survey. In *SOURCE_ACADEMIC*, firms that considered universities, journals or conferences at least somewhat important for idea development activities were coded as “1”, or “0” otherwise.[9] In *COLLAB_ACADEMIC,* firms were coded as “1” if they collaborated with public research institutions and/or approved technological services institutes[10], or “0” otherwise.

DISTANCE controlled for a firm's geographical proximity to the nearest university. Inspired by Boschma et al. (2014), it was based on the logarithm of the road travel time in minutes between the postcodes of the focal firm and the closest university. This logarithm was subtracted from the highest value in the dataset so that “0” corresponded to the firms that were the farthest away from universities. The data used to construct *DISTANCE* were drawn from IDA.

The logistic regressions also included controls for the firms’ structural characteristics. The values for the variables obtained from IDA were based on the data for the largest workplace in each firm:

- Two absorptive capacity controls were included: *RDSALES*, a firms' spending in R&D as a percentage of sales (Laursen and Salter, 2004); and *PATENTS,* which took a value of “1” for firms that reported applying for patents (Mohnen and Hoareau, 2003). The data for *PATENTS* was obtained from the Danish Research and Innovation Survey, and *RDSALES* was based on data from this survey and IDA. *RDSALES* only covered the last year for each wave in the survey because the question on which this variable was based only covered the last year of each wave; however, a comparison of average and median values of *RDSALES* across waves indicated that the firms' R&D intensity did not change substantially over time (those statistics are not presented in this paper). Those firms that reported R&D spending levels equivalent to more than 50% of their sales were excluded, as in Mohnen and Hoareau (2003).
- The logarithm of the total number of employees (*LOGFIRMSIZE*) was used as a proxy for firm size (Laursen and Salter, 2004). The data were obtained from IDA and represent an average for the period covered in each wave. However, for those firms that participated in the 2015 wave, the data covered the period 2012–2014 because the data required to construct this variable were only available until

[5] To determine whether a municipality could be considered part of the core of densely populated municipalities, its area was divided into cells of 1 km^2. If 50% of these cells had population densities above 1500 inhabitants per km^2, the municipality was considered part of this category (OECD, 2012, pp. 26–27).

[6] In January 2019, the OECD list of functional urban areas for Denmark (OECD, n.d.) was updated, no longer including the Esbjerg area; however, the paper used the previous list because the data cover the 2009–2015 period.

[7] An earlier version of this paper included two variables, one capturing whether the firm saw internal knowledge sources as at the least a bit important and the other capturing whether the firm saw internal knowledge sources as very important. However, these have been merged to prevent multicollinearity issues.

[8] 31.27% of the firms reported that internal knowledge sources were somewhat important to them.

[9] Originally, the variable ranged from “0” to “2”, counting whether firms collaborated with one or both types of organisations. However, the number of observations was too small for each level of the variable.

[10] These are government-approved, not-for-profit institutes focused on diffusing new technologies among the Danish industry. As part of their mission, they combine applied research with the provision of services to businesses, such as consultancy or testing services. They also have direct links to universities through informal exchanges between employees or collaborative research projects (Arnold et al., 2007, pp. 105–115).

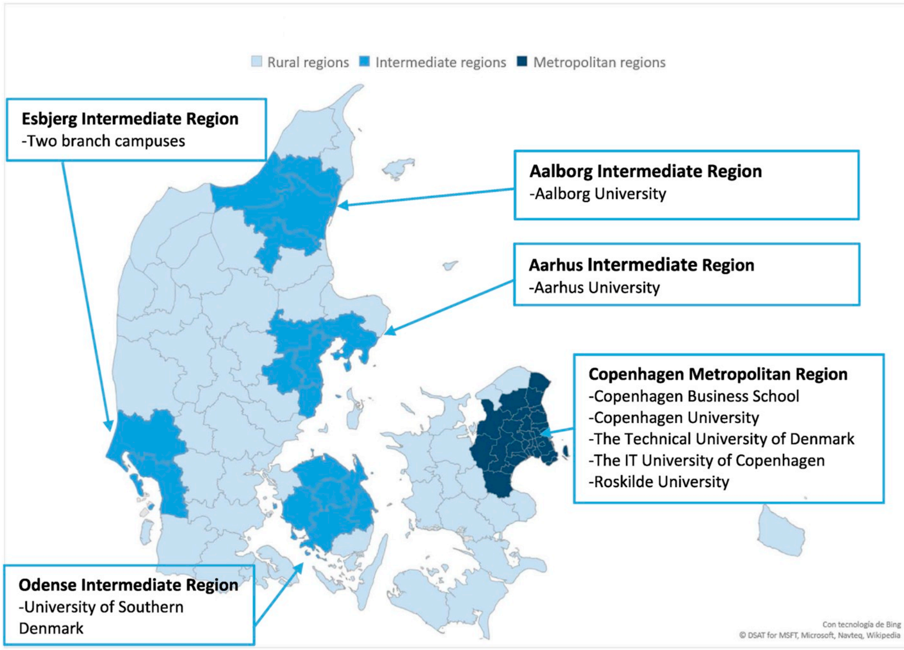

Fig. 1. Types of regions in Denmark. Sources: Danish Ministry of Higher Education and Science, n.d.; OECD, 2012.

2014. A comparison of average and median values of *LOGFIRMSIZE* across waves showed that firm size did not change substantially over time (those statistics are not presented in this paper).

- *INDUSTRY* classified firms in five groups: "0" for other activities, "1" for non-knowledge-intensive services, "2" for low-technology manufacturing, "3" for knowledge-intensive services and "4" for high-technology manufacturing. The benchmark corresponded to firms in low-technology manufacturing. The data were obtained from IDA and covered only the last year of each wave of the Danish Research and Innovation Survey. Cross-tabulations were requested, comparing the proportion of firms that operated in each group for each wave. These proportions did not change substantially over time (those statistics are not presented in this paper). Table A2 in the Appendix shows the industry codes on which *INDUSTRY* was based.

The model is displayed below. For Hypothesis 1 to be supported, *SHAREGRAD*REGION* should be statistically significant and have a positive sign for firms in rural regions. For Hypothesis 2 to be supported, *SOURCE*REGION* and/or *COLLAB*REGION* should be statistically significant and have a positive sign for firms in rural regions. The reference category corresponds to firms in the Copenhagen metropolitan region:

$$\begin{aligned} &COLLAB\_UNIi \\ &=\alpha + \beta_1 REGIONi + \beta_2 SHAREGRADi + \beta_3 (SHAREGRADi * REGIONi) \\ &\quad + \beta_4 COLLABi \\ &\quad +\beta_5 (COLLABi * REGIONi) + \beta_6 SOURCE + \beta_7 (SOURCEi * REGION \\ &\quad i) \\ &\quad +\beta_8 RDSALESi + \beta_9 LOGFIRMSIZEi + \beta_{10} PATENTSi + \beta_{11} COLLAB\_ \\ &\quad ACADEMICi \\ &\quad +\beta_{12} SOURCE\_ACADEMICi + \beta_{13} SOURCE\_INTi + \beta_{14} \\ &\quad DISTANCEi + \beta_{15} INDUSTRYi \\ &\quad + \beta_{16} WAVEi + \varepsilon_{it} \end{aligned}$$

After creating correlation matrices and performing variance inflation factor (VIF) tests, no multicollinearity issues were detected, except for the correlation between *SOURCE* and *SOURCE_ACADEMIC* ($r = 0.68$, significant below the 1% threshold, see Table A3 in the Appendix).

3.5. Descriptive statistics

Table 1 shows that a roughly similar percentage of firms in rural regions collaborated with universities in innovation when compared to firms in the Copenhagen metropolitan region. This was so despite the limited university presence in rural regions and the greater geographical distance between firms in rural regions and universities. Looking at *DISTANCE*, as expected, firms in rural regions were by far the ones that were the farthest away from a nearest university; they had an average travel time above 53 min, almost five times that of their metropolitan counterparts. It should be noted, nevertheless, that 58.39% of the firms in rural regions had engaged in innovation activities, a smaller percentage than that of their metropolitan counterparts (61.95%) and that of firms in intermediate regions (62.61%). The similar percentages of firms in rural regions and in the Copenhagen metropolitan region that collaborated with universities might also relate to the findings from Jakobsen and Lorentzen (2015), who observed that firms in rural regions were more likely to draw on external knowledge through formal channels instead of with informal exchanges. It was in intermediate regions where the largest proportion of firms collaborating with universities was found.

Regarding *SHAREGRAD*, the average share of graduates in firms in rural regions was approximately a third of that of their metropolitan counterparts and half of that of their intermediate counterparts. The differences were starker when comparing the median percentages of graduates, indicating a more skewed distribution of the presence of graduates among firms in rural regions. Also, substantial inter-regional differences were observed in the percentage of firms that employed at least one university graduate, although they did not appear to be as stark as the previous indicators. These differences in *SHAREGRAD* were expected, as one can take into account that graduate employment tends to concentrate in metropolitan regions (Florida, 2002; Gordon and McCann, 2000; McCann, 2008; Rodríguez-Pose and Fitjar, 2013; Scott, 2010; Storper and Scott, 2009).

Notable inter-regional differences were also visible in *RDSALES*, where firms in rural regions' R&D spending over sales was on average less than half that for firms in the Copenhagen metropolitan region; in *SOURCE_ACADEMIC* and *COLLAB_ACADEMIC*, where a higher percentage of firms in rural regions utilised knowledge from university sources and from sources similar to universities, compared to their metropolitan

Table 1
Descriptive statistics and characteristics by type of region.

Dependent Variable	All Firms (N = 4772)		Rural Regions (N = 1680)		Intermediate Regions (N = 1152)		Copenhagen Metropolitan Region (N = 1940)	
		Std Dev		Std Dev		Std Dev		Std Dev
COLLAB_UNI(percent)	8.82%	28.36%	8.57%	28.01%	9.81%	29.76%	8.45%	27.83%
Explanatory Variables								
SHAREGRAD (average)	14.11%	20.71%	6.85%	12.38%	13.98%	20.49%	20.46%	24.23%
SHAREGRAD (median)	4.63%	20.71%	1.84%	12.38%	4.74%	20.49%	11.18%	24.23%
Percent of firms with at least one graduate	65.44%	47.55%	57.32%	49.48%	67.36%	46.91%	71.34%	45.23%
COLLAB (average)	0.72	1.41	0.73	1.44	0.71	1.36	0.72	1.43
SOURCE (average)	3.28	1.81	3.34	1.81	3.33	1.79	3.21	1.81
Control Variables								
DISTANCE (average travel time in minutes to closest university)	26.98	26.65	53.22	25.81	15.06	14.12	11.01	10.43
LOGFIRMSIZE (average)	3.21	1.35	3.32	1.26	3.17	1.32	3.15	1.42
SOURCE_INT (average)	1.35	0.75	1.29	0.74	1.36	0.76	1.39	0.75
SOURCE_ACADEMIC (percent)	67.67%	46.78%	69.17%	46.19%	68.49%	46.48%	65.88%	47.42%
COLLAB_ACADEMIC (percent)	9.51%	29.34%	10.89%	31.16%	9.63%	29.52%	8.24%	27.52%
RDSALES (percent)	2.47%	7.61%	1.44%	5.49%	2.59%	7.93%	3.29%	8.78%
PATENTS (percent)	8.04%	27.21%	8.09%	27.28%	8.85%	28.42%	7.53%	26.38%
INDUSTRY: Other activities (percent)	5.36%	22.53%	6.55%	24.74%	5.64%	23.08%	4.18%	20.01%
INDUSTRY: Non knowledge-intensive services (percent)	29.99%	45.83%	27.62%	44.72%	28.73%	45.27%	32.78%	46.95%
INDUSTRY: Low technology manufacturing (percent)	16.14%	36.79%	26.96%	44.39%	17.19%	37.74%	6.13%	24.01%
INDUSTRY: Knowledge-intensive services (percent)	36.29%	48.09%	21.91%	41.37%	35.51%	47.87%	49.23%	50.01%
INDUSTRY: High technology manufacturing (percent)	12.22%	32.75%	16.96%	37.54%	12.93%	33.57%	7.68%	26.63%
Wave								
WAVE 2009–11 (number of observations)	955		332		233		390	
WAVE 2010–12 (number of observations)	909		336		212		361	
WAVE 2011–13 (number of observations)	919		305		232		382	
WAVE 2012–14 (number of observations)	931		326		215		390	
WAVE 2013–15 (number of observations)	1058		381		260		417	

counterparts; and in *INDUSTRY*, where the highest percentage of manufacturing firms were observed in rural regions, and the highest percentage of service firms was in the Copenhagen metropolitan region.

4. Results

4.1. Main regression analysis

Model 1 (Table 2) shows support for Hypothesis 1, stating that there was a positive association between graduate employment and the likelihood that firms collaborated in innovation with universities, and this association was stronger for firms in rural regions, compared to firms in the Copenhagen metropolitan region. This interpretation was based on the finding that *SHAREGRAD*REGION (rural)* was statistically significant below the 1% level and had a positive sign, the statistical significance and positive sign of *SHAREGRAD* and the lack of statistical significance of *REGION (rural)*. To provide a more meaningful measure of the extent to which graduate employment was associated with industry–university collaboration for firms in rural regions and their metropolitan counterparts, Fig. 2 displays the predicted probabilities. The predicted probabilities were calculated for firms that had average values in the model's continuous variables and were in the reference category for each of the categorical variables. For firms in rural regions, higher values of *SHAREGRAD* were associated with higher probabilities of industry–university collaboration, while for firms in the Copenhagen metropolitan region, practically no change was noted in the probability of collaborating with universities. Note however that the differences between firms in the two types of regions only appeared to be statistically significant at high values of *SHAREGRAD*.

The findings suggest that the relative lack of universities in rural regions might not pose much of an obstacle to firms in those regions collaborating with universities in innovation activities because graduate employees can provide a better understanding of university research and the ways universities work as organisations, facilitating cognitive proximity to the universities. In this sense, the results might reflect Boschma's (2005) suggestion that geographical proximity might be less of a necessity for collaboration to take place when there is cognitive proximity between the parties.

Whereas Model 1 provides support for Hypothesis 1, this was not the case for Hypothesis 2. *COLLAB* was statistically significant below the 1% threshold and had a positive sign, but *COLLAB*REGION (rural)* was not statistically significant, suggesting that there was a positive association between collaborating for innovation with other organisations than universities and industry-university collaboration but that this association was not stronger for firms in rural regions when compared to firms in the Copenhagen metropolitan region.

As for those forms of drawing on external non-university knowledge that do not necessarily entail collaborating with organisations, Model 2 suggests that firms in the Copenhagen metropolitan region were negatively associated with industry–university collaboration, and this association appeared to be stronger for firms in rural regions. *SOURCE* was statistically significant below the 1% threshold and had a negative sign, and *SOURCE*REGION (rural)* was statistically significant below the 1% threshold and had a negative sign. As in *SHAREGRAD*, predicted probability plots had been requested (Figs. 3 and 4) suggesting a similar increase across the regions in the probability to collaborate in innovation with universities with a higher number of types of partners and a similar decrease with a higher number of types of knowledge sources, respectively.

Thus, firms that draw on external non-university knowledge firms in rural regions were not more likely to collaborate with universities than firms in the Copenhagen metropolitan region. Instead, firms that have formal collaboration channels with other organisations were more likely to collaborate with universities, independently of the type of region, and firms that drew on external knowledge sources without necessarily collaborating with them were less likely to collaborate with

Table 2
Logistic regression, likelihood of collaborating with universities in Denmark.

		Model 1	
		Estimate	Standard error
	Intercept	−6.7499***	0.3357
Benchmark: REGION (metro)	REGION (rural)	0.4018	0.2868
	REGION (intermediate)	1.1406***	0.2993
	SHAREGRAD	0.0112***	0.00223
Benchmark: SHAREGRAD*REGION (metro)	SHAREGRAD*REGION (rural)	0.0254***	0.00439
	SHAREGRAD*REGION (intermediate)	−0.0052	0.00367
	COLLAB	0.5540***	0.0383
Benchmark: COLLAB*REGION (metro)	COLLAB*REGION (rural)	0.0312	0.0537
	COLLAB*REGION (intermediate)	0.0348	0.0588
	SOURCE	−0.1365***	0.0519
Benchmark: SOURCE*REGION (metro)	SOURCE*REGION (rural)	−0.1484**	0.0671
	SOURCE*REGION (intermediate)	−0.2240***	0.0727
	RDSALES	0.0535***	0.0039
	LOGFIRMSIZE	0.2680***	0.0373
Benchmark: PATENTS (no)	PATENTS (yes)	1.0244***	0.1197
Benchmark: COLLAB_ACADEMIC (no)	COLLAB_ACADEMIC (yes)	1.8657***	0.0976
Benchmark: SOURCE_ACADEMIC (not important)	SOURCE_ACADEMIC (at the least a bit important)	1.8359***	0.1713
Benchmark: SOURCE_INT (at the least a bit important)	SOURCE_INT (not important)	0.6642***	0.1963
	SOURCE_INT (very important)	0.6930***	0.1082
	DISTANCE	−0.0871**	0.0382
Benchmark: INDUSTRY (low-technology manufacturing)	INDUSTRY (other industries)	1.0552***	0.2222
	INDUSTRY (non-knowledge-intensive services)	−0.2539*	0.1387
	INDUSTRY (knowledge-intensive services)	0.0828	0.1470
	INDUSTRY (high-technology manufacturing)	0.0409	0.1566
Benchmark: WAVE 2009–11	WAVE 2010-12	−0.0603	0.1303
	WAVE 2011-13	−0.4068***	0.1368
	WAVE 2012-14	0.1174	0.1301
	WAVE 2013-15	0.0952	0.1281
	N	4772	
	AIC	4461.467	
	SC	4642.642	
	−2 Log L	4405.467	
	R-Square (Max-rescaled)	0.6489	

*: significant at 10% level, **: significant at 5% level, ***: significant at 1% level.

universities, especially firms in rural regions. Although drawing on external knowledge net of universities might contribute to a firm's ability to draw further external knowledge and achieve cognitive proximity with universities, firms in rural regions were not more likely to collaborate with universities than firms in the Copenhagen metropolitan region. Note, however, that the dataset did not allow for the

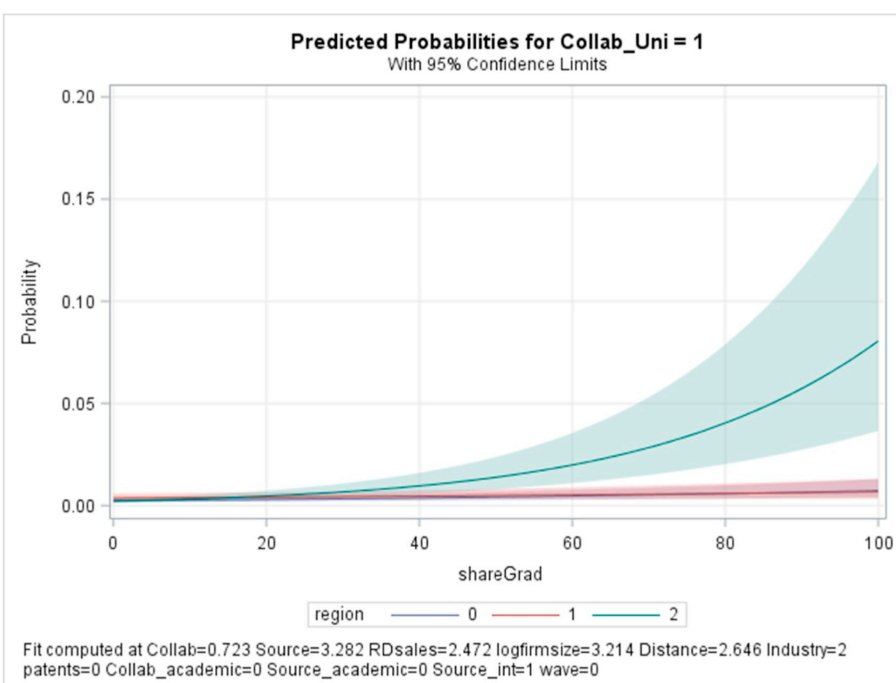

Fig. 2. Predicted probability that firms collaborate with universities at different values of *SHAREGRAD* (with 95% confidence limits).

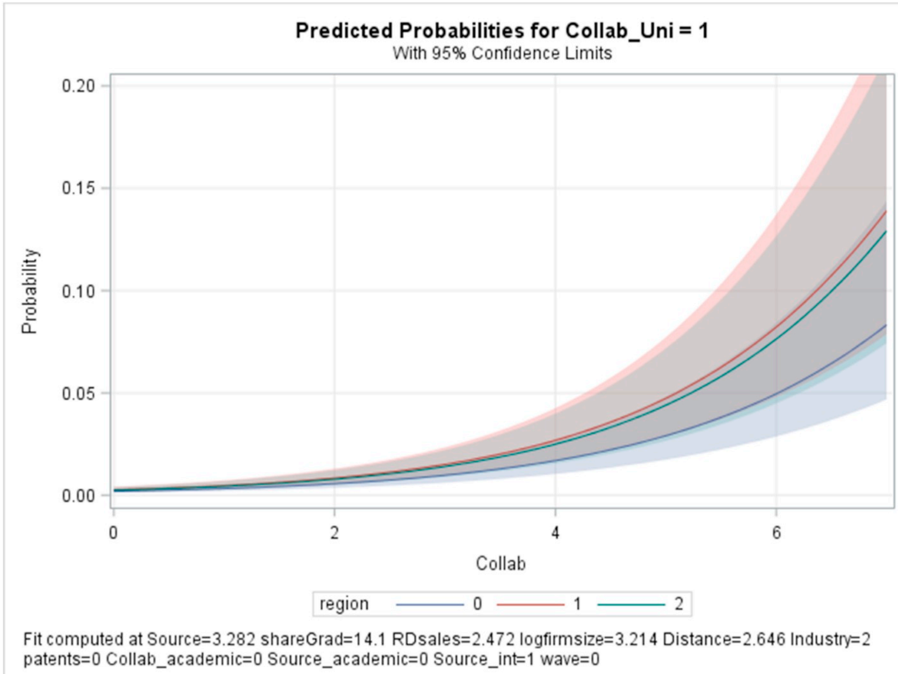

Fig. 3. Predicted probability that firms collaborate with universities at different values of *COLLAB* (with 95% confidence limits).

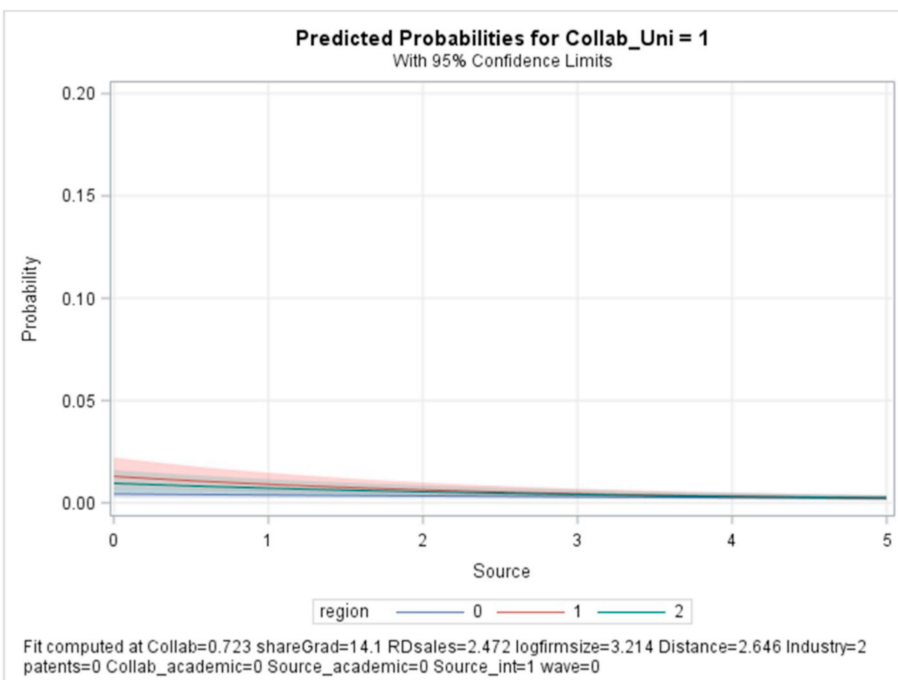

Fig. 4. Predicted probability that firms collaborate with universities at different values of *SOURCE* (with 95% confidence limits).

assessment of whether firms drew on external knowledge inside or outside their region, and thus it is not possible to assess whether firms in rural regions were more likely to maintain extra-regional collaboration channels to offset the organisational thinness of their regions, and whether extra-regional collaborations were particularly associated with industry-university collaboration among firms in rural regions.

Regarding the control variables, the analysis confirmed that firms with higher levels of absorptive capacity measured by R&D intensity and patenting were more likely to collaborate with universities as expected in the industry–university collaboration literature (Laursen and Salter, 2004; Mohnen and Hoareau, 2003), since *RDSALES* and *PATENTS* had a positive sign and were statistically significant. Similarly, it was confirmed that larger firms were more likely to collaborate with universities (Laursen and Salter, 2004).

Firms were more likely to collaborate in innovation with universities if they acquired knowledge similar to that of universities, whether this entailed collaborative relationships as in *COLLAB_ACADEMIC* or not, as in *SOURCE_ACADEMIC*. The model estimated that firms that considered internal knowledge sources very important for idea development were, together with those that did not consider them important, more likely to collaborate with universities, compared to firms that considered them somewhat important. Although firms can combine internal and external knowledge as part of their innovation activities, firms might not necessarily have to draw from internal knowledge while collaborating with universities (Criscuolo et al., 2018), and the results from Model 2 might be a reflection of this diversity in the choice of knowledge sources.

Firms were estimated to be less likely to collaborate with universities the closer they were to the nearest university (*DISTANCE*), and this result was independent of the type of region where the firms were located. Because this variable did not provide information on the location of the focal firm's university partner, the results should be interpreted as an indication that industry-university collaboration was less likely if firms were at a relatively short geographical distance from potential university partners. As for the industry controls, firms in non-knowledge-intensive services were less likely to collaborate with universities than firms in low-technology manufacturing, and the opposite was the case for firms in other industries. Finally, there were some yearly differences in the propensities of firms to collaborate with universities.

4.2. Firms in rural regions within commuting distance of a metropolitan region

Firms in rural regions within commuting distance of a metropolitan region might have easier access to metropolitan regions and thus to universities than more peripherally located firms (Doloreux and Dionne, 2008; Shearmur and Bonnet, 2011). Thus, among firms in rural regions, those firms that were within commuting distance of a metropolitan region might present a special case with geographical proximity being more relevant in facilitating industry–university collaboration, and graduate employees' cognitive proximity to universities being less relevant. Similarly, a greater proportion of these firms might collaborate with universities without having to draw on external knowledge net of universities, since the cognitive proximity that firms obtain by drawing on external knowledge will be less necessary in order to be able to collaborate in innovation with universities.

Model 2 (Table A4 in the Appendix) displays the results of regression models exploring these possibilities. Firms in rural regions located on the island of Zealand have been treated as within commuting distance of the Copenhagen metropolitan region, and firms outside the island of Zealand have been treated as beyond commuting distance (see Figure A1 in the Appendix). Due to space limitations, the analysis presented here focuses only on the explanatory variables and on the differences between the two types of firms in rural regions and their metropolitan counterparts.

Regarding Hypothesis 1 there was a statistically significant positive association between employing university graduates and collaborating in innovation with universities, because *SHAREGRAD* was statistically significant and had a positive sign. This association was stronger among firms in rural regions beyond commuting distance of the Copenhagen metropolitan region than among firms in rural regions within commuting distance, owing to the fact that *REGION (rural beyond metro commuting area)* and *SHAREGRAD*REGION (rural beyond metro commuting area)* also were statistically significant and had positive signs. In contrast, the negative sign of *REGION (rural within metro commuting area)* suggested that firms in rural regions within commuting distance of the Copenhagen metropolitan region were not necessarily more likely to collaborate with universities, even if there was more geographical proximity between these firms and universities.

Regarding Hypothesis 2, drawing on external knowledge net of universities was not associated with a higher likelihood that firms in rural regions collaborated with universities compared to firms in the Copenhagen metropolitan region, whether the firms in rural regions were at commuting distance from Copenhagen or not.

4.3. Robustness tests

In order to assess the robustness of the results, the following specifications of Model 1 have been explored (though not presented in this paper due to space limitations):

- In one specification, *SOURCE* and *SOURCE*REGION* were included, and *COLLAB* and *COLLAB*REGION* were excluded; in another *COLLAB* and *COLLAB*REGION* were included, whereas *SOURCE* and *SOURCE*REGION* were excluded. This however did not lead to a change in the sign and statistical significance of the remaining regression estimates. Nevertheless, the results showed that *COLLAB* and *COLLAB*REGION* increased the model's explanatory power to a greater extent than *SOURCE* and *SOURCE*REGION*, suggesting that the firms that had the capabilities to engage in collaborative relationships with other organisations were also more likely to have the capabilities to collaborate with universities (Hewitt-Dundas et al., 2019; Perkmann and Walsh, 2007).
- In another specification, *COLLAB* included all the types of organisations grouped in *COLLAB_ACADEMIC,* and *SOURCE* all the knowledge sources that could be reported by the survey participants, except for universities and scientific journals (which were included in separate control variables). The interaction between *SOURCE* and *REGION (rural)* lost statistical significance, but this had no consequences for the findings in relation to the hypotheses.
- Labour markets for university graduates are thinner in rural regions, compared to metropolitan locations (Scott, 2010; Storper and Scott, 2009). In locations where firms tend to employ relatively few university graduates like rural regions, employing one additional university graduate might increase the likelihood of collaborating with universities, whereas in locations where firms tend to employ a relatively large number of university graduates, like the Copenhagen metropolitan region, employing more university graduates might not measurably increase the chances of collaborating with universities. To test for this possibility, an additional model included the quadratic term *SHAREGRAD*SHAREGRAD* in addition to *SHAREGRAD.* A positive, statistically significant interaction between *SHAREGRAD*SHAREGRAD* and *REGION* for firms in rural regions would point to decreasing returns to the likelihood of collaborating with universities among firms in the Copenhagen metropolitan region. However, the interaction term of *SHAREGRAD*SHAREGRAD* and *REGION (rural)* had a negative sign, suggesting that firms in the Copenhagen metropolitan region employing additional university graduates were associated with increasing returns to the likelihood of collaborating with universities.
- Excluding from Model 1 those firms that participated in the 2015 wave did not affect the results.
- Finally, the results from Model 1 did not change if interaction terms of *INDUSTRY* and *REGION* were included.

5. Discussion and conclusion

The findings of this paper contribute to the exploration of how industry–university collaboration in innovation takes place in different types of regions. In doing so, they add to a literature that until recently mostly focused on factors associated to industry-university collaboration independent of regional location (D'Este et al., 2013; D'Este and Iammarino, 2010; Johnston and Huggins, 2016). Firms in rural regions that employed university graduates were more likely to collaborate with universities than similar firms in the Copenhagen metropolitan region. Among firms in rural regions, not having universities in their regions might not be so much of an obstacle to industry–university collaboration if these firms rely on the cognitive proximity to universities that graduate employees can provide. University graduates might not just contribute to their firms' absorptive capacity but might also provide knowledge of the research conducted at universities and how universities operate as organisations.

Previous research has already pointed out that the association between geographical proximity and industry–university collaboration might be explained by graduate employees' cognitive proximity to university research and social proximity to staff from universities (Breschi and Lissoni, 2001; Drejer and Østergaard, 2017; Østergaard, 2009). This paper provides a deeper understanding of the role of cognitive proximity for industry–university collaboration in rural and metropolitan regions. There is also the possibility that graduate employees' social ties to staff at their *alma mater* institutions are particularly relevant to linkages between firms in rural regions and universities; however, *SHAREGRAD* did not allow the assessment of whether this was the case. In order to do so, future research could follow an approach similar to that of Drejer and Østergaard (2017), running separate regressions on the likelihood that firms collaborate with each of the Danish universities and replacing *SHAREGRAD* with an explanatory variable that measures the share of employees educated at each focal university. Compared to *SHAREGRAD*, this variable should be better able to capture any association related to the social proximity between firms and the focal university. If firms in rural regions that employ graduates from a specific university are more likely to collaborate with it, this might be because these graduates have social ties with staff at the university. A second explanatory variable could measure the share of employees educated at other universities than the focal one. Because these employees would not have received training at the focal university, this variable would capture whether these employees contribute to the firm's ability to integrate university knowledge, that is the cognitive proximity to universities. Nevertheless, this approach would not be without challenges. For example, because there would be fewer observations with positive values in the dependent and explanatory variables, it is less likely that the models could detect any relations between them.

An alternative approach to the challenge of discerning whether and how graduate employment can be relevant to cognitive and social proximity between firms in rural regions and universities might entail complementing quantitative research like the present one with case studies. Because the present paper cannot propose causal relationships owing to its cross-sectional nature, a case study would allow exploration as to whether and how graduate employees' social ties to university staff might contribute to social proximity between a firm and the universities where these employees obtained their degrees. Case studies would also enable the further exploration of how graduate employees might be more conducive to the formation of cognitive proximity between their firms and university research and would be useful in providing theoretical explanations for why firms in rural regions beyond the commuting area of the Copenhagen region were actually more likely to collaborate with universities than their metropolitan counterparts, even when comparing firms that *did not employ* university graduates (Model 2). For now, a potential explanation might be that firms in this type of rural region were more likely to collaborate for innovation, because unplanned, informal exchanges were insufficient to acquire the knowledge they needed as part of their innovative processes (Jakobsen and Lorentzen, 2015).

In line with previous research (Drejer and Østergaard, 2017; Hewitt-Dundas et al., 2019; Laursen and Salter, 2004), this paper confirmed that firms might collaborate with organisations other than universities as part of their knowledge acquisition strategies and that drawing on external knowledge net of universities might help them decrease the cognitive distance with universities—and decrease the importance of geographical proximity—by increasing the knowledge-sourcing capabilities of firms. Taking into account that firms in rural regions are farther away from universities than their metropolitan counterparts, drawing on external non-university knowledge was expected to be particularly supportive to industry-university collaboration among firms in rural regions; however, this did not seem to be the case. Drawing on external knowledge net of universities by collaborating with different types of organisations (Drejer and Østergaard, 2017; Hewitt-Dundas et al., 2019) was positively associated with industry–university collaboration, whereas this association was negative when it came to draw on external non-university knowledge without necessarily collaborating with other organisations. Note however that the dataset did not allow for the differentiation of whether firms' knowledge acquisition strategies involved links with extra-regional organisations and that previous research has pointed out that firms in relatively isolated locations are more likely to collaborate for innovation with extra-regional partners than firms in metropolitan regions (Grillitsch and Nilsson, 2015). Hence, the present results might benefit from complementary research with datasets that allow for the identification of whether the focal firm's external partners are within or outside the firm's region. In that way, it would be possible to further assess whether drawing external non-university knowledge through extra-regional partners was more conducive to industry-university collaboration among firms in rural regions. Furthermore, in that way, it would also be easier to propose theoretical explanations for why drawing on external knowledge net of universities was similarly associated to industry-university collaboration among firms in rural regions and in the Copenhagen metropolitan region.

While the present paper would benefit from further research discerning theoretical explanations for its findings, cross-country research could extend its generalisability. This was a single-country study and a firm's perception of geographical distance with universities might differ in larger, more sparsely populated Nordic countries such as Sweden, Norway and Finland. Furthermore, Copenhagen is the only metropolitan region in the country, and its nature as a political capital might also influence the results. These limitations provide additional opportunities for research. Cross-country research involving larger, more sparsely populated countries, as well as countries with more metropolitan regions than just the nation's capital, could contribute to determining whether the associations observed in the present study hold in other contexts.

The results suggest interesting implications for the design of industry–university collaboration policies and further legitimise the university's mission as a provider of highly skilled employees to regional firms and as a promoter of firm innovation and regional development (Charles, 2006; Evers, 2019; Nilsson, 2006). Policies that promote firms in rural regions drawing on external non-university knowledge might also contribute to the cognitive proximity of firms to universities, helping to further connect firms in rural regions and universities, but the results indicate that these policies might be similarly effective for firms in the Copenhagen metropolitan region. In addition, initiatives that support graduate employment in rural regions might not only contribute to the absorptive capacity of these firms (Drejer and Østergaard, 2017) but might also be particularly supportive to incentivise links between these firms and universities. An example of these policies could be the introduction by the Danish government in 2016 of a two-year subsidy to firms in rural areas that employ highly skilled professionals for innovation projects (Knudsen et al., 2018, p. 17).

CRediT authorship contribution statement

David Fernández Guerrero: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration.

Declaration of competing interest

Declarations of interest: none.

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Appendix

Table A1
List of Municipalities per Functional Urban Area

Functional Urban Area	Municipalities
Copenhagen Metropolitan Area	Albertslund, Allerød, Ballerup, Brøndby, Copenhagen, Dragør, Egedal, Fredensborg, Frederiksberg, Frederikssund, Furesø, Gentofte, Gladsaxe, Glostrup, Greve, Helsingør, Herlev, Hillerød, Hvidovre, Høje-Taastrup, Hørsholm, Ishøj, Køge, Lejre, Lyngby-Taarbæk, Roskilde, Rudersdal, Rødovre, Solrød, Tårnby, Vallensbæk
Aarhus	Aarhus, Favrskov, Odder, Skanderborg, Syddjurs
Odense	Assens, Faaborg-Midtfyn, Kerteminde, Nordfyns, Nyborg, Odense
Aalborg	Aalborg, Brønderslev, Jammerbugt, Rebild
Esbjerg	Esbjerg, Fanø, Varde

Table A2
Industry Classifications

Industry Variable	Industry Aggregations	NACE Rev.2 Branch Codes
Other activities	Primary sector	(01) Crop and animal production, hunting and related service activities; (02) forestry and logging; (03) fishing and aquaculture; (05) mining of coal and lignite; (06) extraction of crude petroleum and natural gas; (07) mining of metal ores; (08) other mining and quarrying; (09) mining support service activities.
	Utilities	(35) Electricity, gas, steam and air conditioning supply; (36) water collection, treatment and supply; (37) sewerage; (38) waste collection, treatment and disposal activities; materials recovery; (39) remediation activities and other waste management services.
	Construction	(41) Construction of buildings; (42) civil engineering; (43) specialised construction activities.
Low technology manufacturing	Low technology manufacturing	(10) Manufacture of food products; (11) manufacture of beverages; (12) manufacture of tobacco products; (13) manufacture of textiles; (14) manufacture of wearing apparel, except fur apparel; (15) manufacture of leather and related products; (16) manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials; (17) manufacture of paper and paper products; (18) printing and reproduction of recorded media; (31) manufacture of furniture; (32) other manufacturing.
	Medium-low technology manufacturing	(19) Manufacture of coke and refined petroleum products; (22) manufacture of rubber and plastic products; (23) manufacture of other non-metallic mineral products; (24) manufacture of basic metals; (25) manufacture of fabricated metal products, except machinery and equipment; (33) repair and installation of machinery and equipment.
High technology manufacturing	Medium-high technology manufacturing	(20) Manufacture of chemicals and chemical products; (27) manufacture of electrical equipment; (28) manufacture of machinery and equipment; (29) manufacture of motor vehicles, trailers and semi-trailers; (30) manufacture of other transport equipment.
	High technology manufacturing	(21) Manufacture of basic pharmaceutical products and pharmaceutical preparations; (26) manufacture of computer, electronic and optical products.
Industry Variable	Industry Aggregations	NACE Rev.2 Branch Codes
Knowledge-intensive services	Knowledge-intensive services	(50) Water transport; (51) air transport; (58) publishing activities; (59) motion picture, video and television programme production, sound recording and music publishing activities; (60) programming and broadcasting activities; (61) telecommunications; (62) computer programming, consultancy and related activities; (63) information service activities; (64) financial service activities, except insurance and pension funding; (65) insurance, reinsurance and pension funding, except compulsory social security; (66) activities auxiliary to financial services and insurance activities; (69) legal and accounting activities; (70) activities of head offices and management consultancy activities; (71) architectural and engineering activities and technical testing and analysis; (72) scientific research and development; (73) advertising and market research; (74) other professional, scientific and technical activities; (75) veterinary activities; (78) employment activities; (80) security and investigation activities; (84) public administration and defence and compulsory social security; (85) education; (86) human health activities; (87) residential care activities; (88) social work activities without accommodation; (90) creative, arts and entertainment activities; (91) libraries, archives, museums and other cultural activities; (92) gambling and betting activities; (93) sports activities and amusement and recreation activities.
Non-knowledge-intensive services	Non-knowledge-intensive services	(45) Wholesale and retail trade and repair of motor vehicles and motorcycles; (46) wholesale trade, except for motor vehicles and motorcycles; (47) retail trade, except for motor vehicles and motorcycles; (49) land transport and transport via pipelines; (52) warehousing and support activities for transportation; (53) postal and courier activities; (55) accommodation; (56) food and beverage service activities; (68) real estate activities; (77) rental and leasing activities; (79) travel agency, tour operator reservation service and related activities; (81) services to buildings and landscape activities; (82) office administrative, office support and other business support activities; (94) activities of membership organisations; (95) repair of computers and personal and household goods; (96) other personal service activities; (97) activities of households as employers of domestic personnel; (98) undifferentiated goods- and services-producing activities of private households for own use; (99) activities of extraterritorial organisations and bodies.

Table A3
Correlation Matrix of Explanatory and Control Variables

	1. DISTANCE	2. SHAREGRAD	3. COLLAB	4. SOURCE	5. LOGFIRMSIZE	6. RDSALES
1.	1					
2.	0.19***	1				
3.	0.03**	0.12***	1			
4.	0.01	0.05***	0.19***	1		
5.	−0.16***	−0.13***	0.06***	0.07***	1	

6.	0.09***	0.21***	0.18***	0.07***	−0.13***	1
7.	0.08***	0.13***	0.23***	0.52***	0.15***	0.15***
8.	0.03***	0.03**	0.49***	0.12***	0.09***	0.11***
9.	0.01***	0.07***	0.17***	0.68***	0.01	0.08***
10.	−0.02***	0.03**	0.15***	0.08***	0.12***	0.09***
11.	0.09***	0.25***	0.07***	0.08***	−0.25***	0.19***
12.	0.17***	0.11***	−0.01	0.01	−0.04***	0.01
13.	0.52***	0.26***	−0.01	0.04**	−0.09***	0.09***

	7. SOURCE_INT	8. COLLAB_ACADEMIC	9. SOURCE_ACADEMIC	10. PATENTS	11. INDUSTRY	12. WAVE	13. REGION
1.							
2.							
3.							
4.							
5.							
6.							
7.	1						
8.	0.42***	1					
9.	0.56***	0.58***	1				
10.	0.36***	0.52***	0.35***	1			
11.	0.16***	0.15***	0.13***	0.29***	1		
12.	0.01	0.09***	0.04*	0.03	0.01	1	
13.	0.08***	−0.08***	−0.05**	−0.02	0.02	−0.01	1

*: significant at 10% level, **: significant at 5% level, ***: significant at 1% level.

Table A4
Logistic Regression, Likelihood of Collaborating with Universities in Denmark. REGION (metro) as Benchmark

		Model 2	
		Estimate	Standard error
	Intercept	−6.7506***	0.3367
Benchmark: REGION (metro)	REGION (rural beyond metro commuting area)	0.7307**	0.2920
	REGION (rural within metro commuting area)	−2.2276***	0.8107
	REGION (intermediate)	1.1513***	0.3008
	SHAREGRAD	0.0112***	0.00223
Benchmark: SHAREGRAD*REGION (metro)	SHAREGRAD*REGION (rural beyond metro commuting area)	0.0233***	0.00479
	SHAREGRAD*REGION (rural within metro commuting area)	0.0477***	0.0112
	SHAREGRAD*REGION (intermediate)	−0.00519	0.00368
	COLLAB	0.5525***	0.0383
Benchmark: COLLAB*REGION (metro)	COLLAB*REGION (rural beyond metro commuting area)	0.0565	0.0569
	COLLAB*REGION (rural within metro commuting area)	0.0221	0.1102
	COLLAB*REGION (intermediate)	0.0338	0.0588
	SOURCE	−0.1407***	0.0520
Benchmark: SOURCE*REGION (metro)	SOURCE*REGION (rural beyond metro commuting area)	−0.2031***	0.0701
	SOURCE*REGION (rural within metro commuting area)	0.2583	0.1676
	SOURCE*REGION (intermediate)	−0.2266***	0.0729
	RDSALES	0.0535***	0.00387
	LOGFIRMSIZE	0.2627***	0.0375
Benchmark: PATENTS (no)	PATENTS (yes)	1.0170***	0.1201
Benchmark: COLLAB_ACADEMIC (no)	COLLAB_ACADEMIC (yes)	1.8754***	0.0984
Benchmark: SOURCE_ACADEMIC (not important)	SOURCE_ACADEMIC (at the least a bit important)	1.8422***	0.1708
Benchmark: SOURCE_INT (at the least a bit important)	SOURCE_INT (not important)	0.6007***	0.1988
	SOURCE_INT (very important)	0.7112***	0.1091
	DISTANCE	−0.0935**	0.0381
Benchmark: INDUSTRY (low technology manufacturing)	INDUSTRY (other industries)	1.0786***	0.2248
	INDUSTRY (non-knowledge-intensive services)	−0.1819	0.1405
	INDUSTRY (knowledge-intensive services)	0.1069	0.1485
	INDUSTRY (high technology manufacturing)	0.0508	0.1578
Benchmark: WAVE 2009–11	WAVE 2010-12	−0.0512	0.1305
	WAVE 2011-13	−0.3841***	0.1370
	WAVE 2012-14	0.1036	0.1306
	WAVE 2013-15	0.1186	0.1287
	N	4772	
	AIC	4412.409	
	SC	4619.466	
	−2 Log L	4348.409	
	R-Square (Max-rescaled)	0.6538	

*: significant at 10% level, **: significant at 5% level, ***: significant at 1% level.

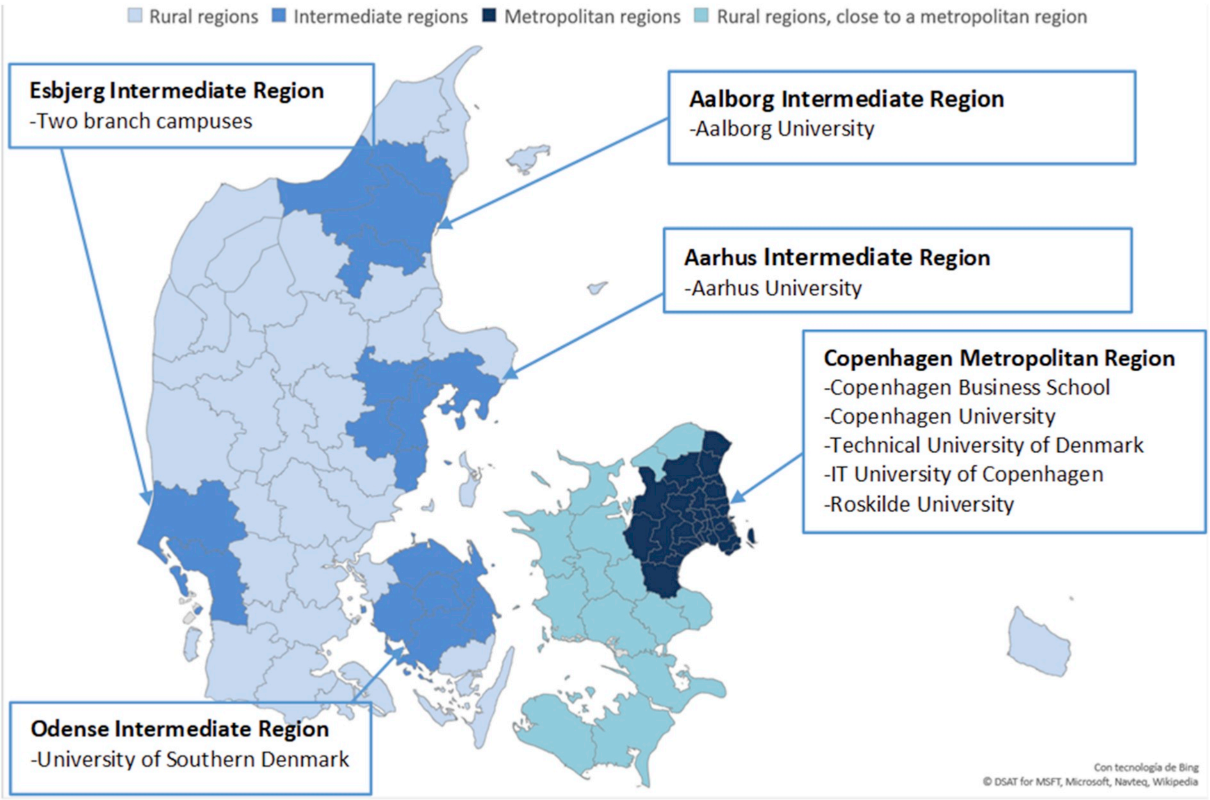

Figure A1. Types of rural regions in Denmark. Sources: Danish Ministry of Higher Education and Science, n.d.; OECD, 2012.

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